DEVELOPING STUDENTS' UNDERSTANDING AND THINKING PROCESS BY MODEL CONSTRUCTION

ÖĞRENCİLERİN ANLAMA VE DÜŞÜNME MEKANİZMALARININ MODEL OLUŞTURMA YOLUYLA GELİŞTİRİLMESİ

Ayse OĞUZ*

ABSTRACT: There is growing recognition that models play a fundamental role in the comprehension of science concepts. This paper aims at enhancing students' understanding and thinking by model construction. Seventh grade middle school students from an urban public school participated in this study as a part of their weekly science club that met after the regular school hours. During the course of the study, the students investigated several common environmental factors about animals by collecting data, made drawings, constructed objects, and wrote journals. The use of journals allowed them to reflect on their experience and the abstract concepts. It also allowed the researchers to have indirect access to the models underlying the meanings students were making every week. Students developed initial models, came up with analogies, and constructed newer models by improving the initial ones. The findings show that model criticism and modification processes are promising activities for science education.

Keywords: model construction, inquiry teaching, science education

ÖZET: Günümüzde modellerin fen kavramlarının anlaşılmasında temel rol oynadığı yaygın biçimde kabul görmektedir. Bu çalışma öğrencilerin anlama ve düşünmelerini model oluşturma yöntemi ile geliştirmeyi amaçlamaktadır. Bu çalışma bir merkez ilköğretim devlet okulu 7. sınıf öğrencileri ile okul sonrası etkinliği çerçevesinde gerçekleştirilmiştir. Çalışma sürecinde, öğrenciler hayvanlara ait ortak çevresel faktörleri veri toplama, resimleme, cisim tasarlama ve gözlem raporu hazırlama yolu ile araştırırlar. Gözlem raporlarının hazırlanması öğrencilerin deneyimlerini ve soyut kavramları ifade etmelerine olanak sağlamaktadır. Buna ilave olarak öğrencilerin deney raporları araştırmacının dolaylı olarak öğrencilerin zihinlerinde oluşturdukları modelleri anlamasına fırsat sağlamaktadır. Öğrenciler ilk etapta oluşturdukları modelleri benzeşim yoluyla yeni modellere dönüştürerek geliştirmektedir. Bulgular model oluşturma ve geliştirme yönteminin fen öğretimine olumlu katkı sağlayacağını göstermektedir.

Anahtar Sözcükler: model oluşturma, araştırmaya dayalı öğretim, fen bilgisi eğitimi

1. INTRODUCTION

The general definition of model is a simplified representation of a system, which concentrates attention on specific aspects of the system (Ingham & Gilbert,1991). Moreover, models enable aspects of the system, i.e., objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible (Gilbert, J. 1995).With these definitions in mind, model building process can be expressed as an organizer for understanding scientific knowledge and process. Further, it means developing a conceptual structure through to assess the legitimate and illegitimate claims of science (Gilbert, 1988). Thus, model building process reflects formulating questions and seeking answers through observation, interpretation, problem-solving and critical thinking.

One of the most significant problems in teaching is to construct the knowledge in the mind of students. From the cognitive perspective, learning is a structure of mental representations, which is organized according to the general reasoning principles (Anderson, Boyle, & Lewis, 1990; White, 1993). Likewise, learning via model building supports the idea that cognitive factors are involved in the process (Boulter, 1998; Clement, 1988; Clement, 2000). In addition, it is any implementation that brings together information resources, learning activities, and instructional strategies.

Several studies proposed different explanations for understanding model and model building process. On the one hand, Clement (1985) examined the model revision, and on the other hand, Gilbert

* Dr., Muğla Üniversitesi, ayseoguz@mu.edu.tr

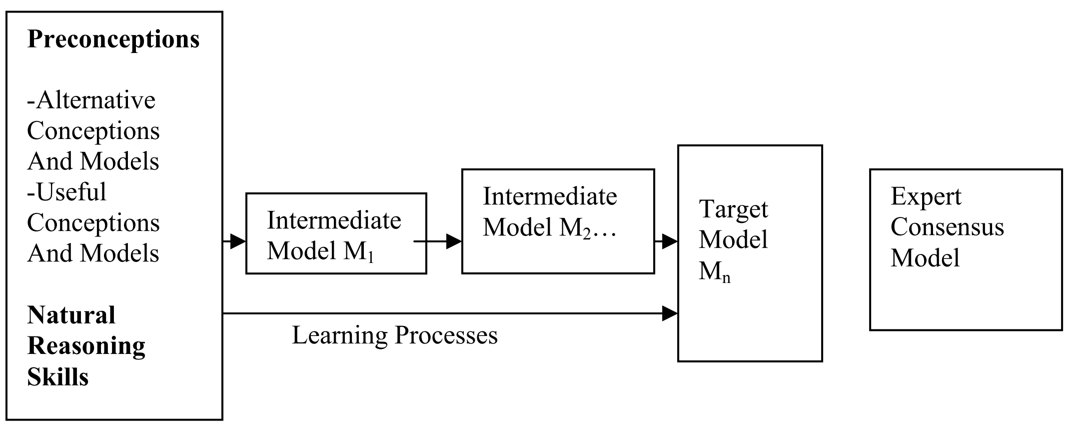
(1988, 1999) focused on model-based teaching and learning. All these studies agreed on modeling as a promising technique for helping students learn new concepts. However, scientists often think of model exclusively as a theoretical explanatory model which reveals a description of hidden processes. For instance, the explanatory model explains how gas molecules move and tries to find answers for "why" questions about where observable changes in temperature and pressure come from. Therefore, causal relationships are often central in such models. However, the model adds not only significant explanatory power to one's knowledge, but also heuristic power, which stimulates the future growth of theory.

1.1. How Can a Model Be Used and Formed?

Most theorists choose to accept the idea that an external world exists and can be operated upon, even if we can never be sure that we are aware of its true nature. What is important is the understanding that our perceptions of existence are the products of internal representations and mental models (Johnson & Laird, 1983) rather than incoming stimuli alone. All perceptions, whatever their source, are filtered through the brain and given meaning by the generative processes occurring there (Osborne & Wittrock, 1983). Learning is not just additive; learning is a process of model building. Moreover, the encoding of our perceptions, or translations of our perceptions, is a model building process. "What are the mental processes that are formed by the individual? Can they be generalized?" The answer to these questions can enable better understanding of the model of mental processes.

A transformation of knowledge in a new situation occurs when the subject alters features previously assumed to be fixed in an existing problem representation to create a new representation. The model in Figure 1 represents Clement`s (1985) approach about target model construction.

Figure 1: Model Construction (Clement, 1985, p.3).



As seen in the figure, people first construct their initial model in terms of their observations and models elements. Gilbert (1999) described this mental representation as follows:

1. Proposition: A proposition is a mental representation consisting of a string of symbols. They are most commonly experienced as words in sentences, spoken or unspoken. For example, the assertion "cats have fur" is a proposition consisting of three symbols (words) corresponding to understood objects or relationships. Mathematic formulas are also considered to be propositions.
2. Mental model: Propositions have a little meaning by themselves; rather they must be interpreted in a larger framework. That framework is the mental model, a complex mental representation with nodes, attributes, and relationships corresponding to receive from world.
3. Image: The image is a perceptual correlate of a mental model from a particular perspective. The image is incomplete: it only represents certain attributes of the complete model. Images created from our perceptions may be integrated into one or more appropriate mental models and stored as records of events.

Compared with Clement (1985) and Gilbert (1999), the major contribution of these papers lie in the logical and empirical linking of the learning goals and resulting knowledge of the learner instead of desired knowledge of someone wishes with the representations to which one had access.

Buckley (2000) provided a case study of a student's mental model building of the circulator system in biology. In this research not only has the author presented some valuable new information about model building learning, but the researcher has also presented it in a very clear and coherent manner with the classroom-based study. Moreover, the roles of learning activities and representations in model-building learning were examined by describing the representations. Each representation about the structure, function, behavior or mechanism of circular system was described.

Thus far, the possibility of how one evaluates knowledge and the mental processes of models that are formed by individuals are explained. In these papers, there is only one way, which aims to get the target model. However, in classroom environment there is more than that. Students are not only learning the new subject matter but also the procedure of getting new knowledge by using strategies. This study aims to suggest that model-based teaching and learning is not only a way of learning new scientific knowledge but it is also a way of leading students to a range of major new scientific concepts. This can be thought as a learning cycle, which feeds students' curiosity and encourages them to learn more.

In short, even though the process of learning via-model construction plays an important role in science education, it receives little attention in the field. In classroom environment, while students are learning the new subject matter, they are also learning the procedure of getting new knowledge by using strategies. Therefore, the purpose of this study was to understand middle school students' model of experimental design strategies about the bugs` and goldfish's reaction to environmental factors.

2. METHOD

2.1. Subject

The data upon which this research is based was drawn from nine girl students who participated in this study as a part of their weekly science club that meets after the regular school hours. All the students were drawn from seventh grade in an urban public middle school. They participated in the study voluntarily and the study was conducted one and a half hour, two-days a week, for ten weeks during spring semester.

One of the goals of the science club was enabled students to attend more science activities. Maybe therefore, students whose science grade average or above the average would like to attend the science club. Since the study was a voluntarily after school activity, the researcher could not control the participants.

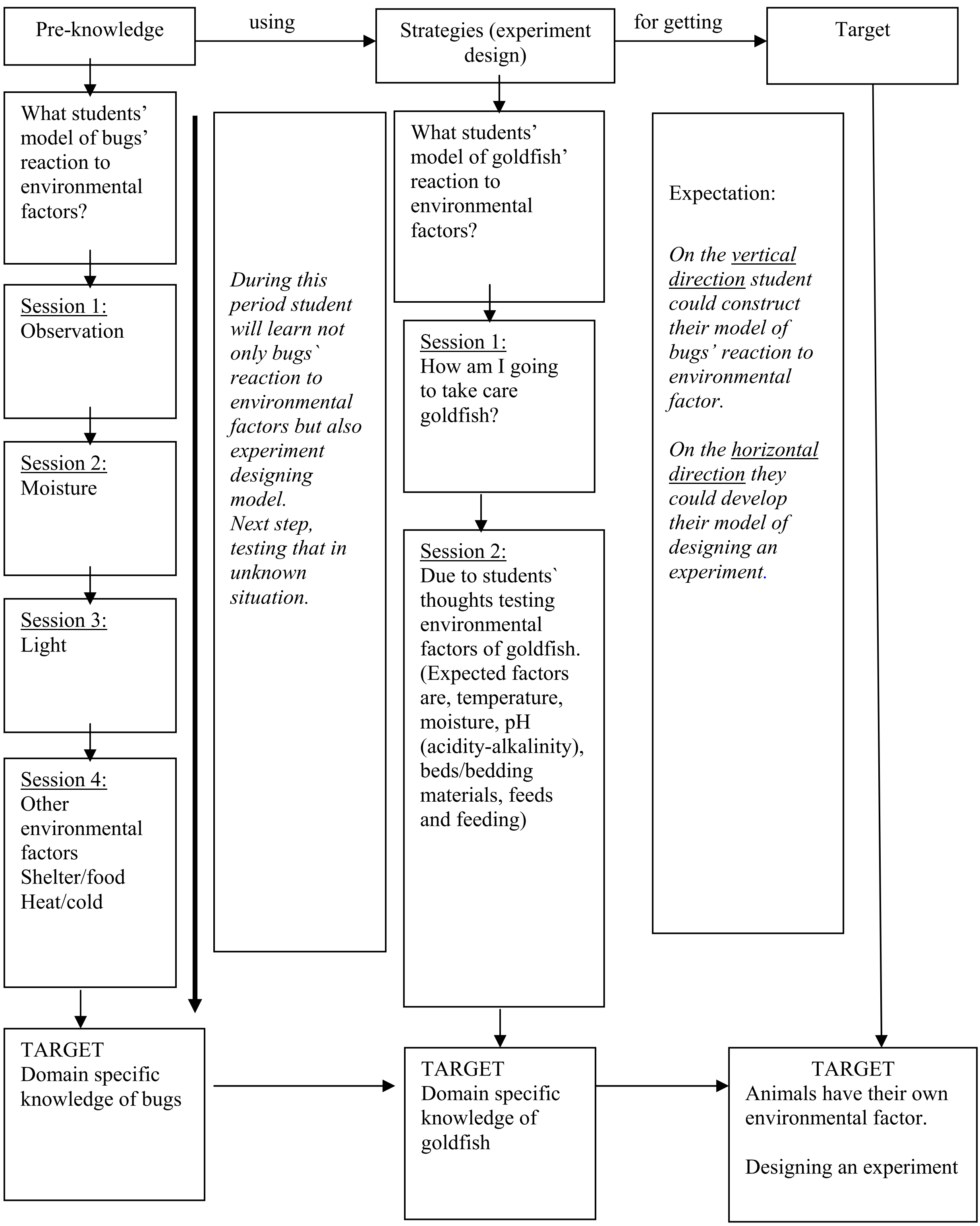
2.2. Procedure

During each session, a similar procedure was followed. In sessions, students were given short texts describing the problem. In the first text, they were requested to design an experiment or make an observation to find out bugs` reaction to environmental factors. The aim of the first text was to understand their pre-model of designing an experiment. Following the first activity, they were given a tutoring text in order to help students organize their ideas. This session was named as intermediate formation. Consequently, they were expected to learn about not only the bugs' environmental preferences, but also designing an experiment. During this session, since they are excellent classroom animals, isopods and beetles were used. They exhibit interesting behaviors, they are small but not tiny, they do not bite, and smell, fly, or jump, and they are easy to be taken care of.

The next step was testing the students` strategies in an unknown situation. The unknown situation, goldfish's reaction to environmental factors, was created to test the representation of students' model of designing an experiment.

The research plan is summarized in Figure 2. In this design, the researcher suggest two directions, one is *vertical direction* that students could construct their model of bugs' and goldfish's reaction to environmental factors and *horizontal direction* that they could develop their model of designing an experiment that is tested by the model of goldfish.

Figure 2: Flowchart for Research Plan



2.3. Coding

All data were in the form of paper and pencil. Iterative process of open coding was used to analyze the data (Strauss & Corbin, 1998). The coding scheme is shown in Table 1. The coding scheme contracted by two researchers. One was a professor and the other one was a doctorate student in a college of education. To establish the reliability, each data were analyzed depending on the coding scheme by the researchers.

Table 1: Coding Protocol

CATEGORIES	
A Experiment Design 1-Logical stage a-research question b-identifying and labeling the variables as: independent dependent control 2-Methodological stages: Designing and Measurement a-identifying techniques for manipulating and controlling variables b-identifying and describing procedures for observation and measurement	B Observation/Inference 1-Procedure a-comparison b-focus: Behavioral/physical 2-Description 3-Inference

In experiment design and observation/inference sections, each student's data are coded with "present" or "not present" in line with categories. For instance, if students have successfully identified the control variables, it is coded with "present" and consequently with "not present" if they have not successfully identified the control variables. An example of coding from student 9`s data are presented in Table 2.

Table 2: Observation/Inference Section Coding Example

Observation/Inference	Student9's response (arbitraged)	Coding
1- Procedure		
a-comparison	…slower than beetle…	Present
b1-behavioral observation	…both bugs` leg are… Beetles move when something near it	Present
b2-physical observation	beetle have three parts (head, abdomen, thorax)	Present
2-Description	…(rolly polly) outer shell that rolls up for protection like an armadillo	Present (more than three)
3-Inference	I conclude that pill bugs rolls up for protection…	Present (three)

3. RESULTS

Students` models of designing an experiment and reasoning skills are shown in Table 3 and Table 4, respectively. In columns, the categories of students` data are presented and in rows each session's activities are coded as A and B. A1, A2, and A3 are sessions related to bugs` activities: observation, bugs' response to moisture and light, respectively. B is the unknown situation, goldfish activity. Each model component observed in data is represented as the number of students. *N* refers to the number of students present for the corresponding session.

Table 3: Students` Progress in Designing an Experiment

Experiment Design	A2	A3	B
	N=9	N=6	N=8
1.Logical stage			
a. research question	6	6	8
b. identifying variables	6	6	8
Independent	2	3	6
Dependent	2	3	6
Control	1	5	5
2.Methodological stage			
a. identifying techniques	4	4	5
b. identifying procedure	4	4	3

Table 4: Students` Reasoning Process

Observation/Inference	A1	A2	A3	B
	N=8	N=9	N=6	N=8
1. Procedure				
A. Comparison	3	9	5	8
B1. Physical obs.	7	9	5	8
B2. Behavioral obs.	7	6	5	8
2. Description	8	9	6	8
One	0	1	0	0
Two	0	2	1	0
Three	0	0	0	8
More than three	8	6	5	0
3. Inference	4	5	6	8
One	1	2	3	2
Two	3	2	2	4
Three	0	1	1	2

Description and inference sections are divided into subsections representing the number of comments students made for each category. For instance, overall four students out of eight present in session A1 made inferences. Only one student made one inference while the remaining made two. This approach will enable us to understand the development of students reasoning throughout the study.

3.1. Students' Model of Experiment Design about Bugs' Reaction to Environmental Factors

3.1.1. Session A1: Observation

The data from this task were chosen to examine students` model of observing beetles and isopods. Results from this session suggested that only three out of eight students made comparisons while observing animals. On the other hand, all the students explained the physical appearance or behavioral pattern of each animal. Four students out of eight made at least one inference in their observation. The relevant parts of a student's journal are italicized as follows:

Student8: *when pill bug is scared it rolls up into a ball. The outer shell that rolls up for protection.*

Next, the procedure of observation sheet was handed out to the students for revising. The effect of tutoring on student will be examined in the following sessions.

3.1.2. Session A2: Responding to moisture

As previously stated, the second session was about bugs` moisture preferences. The following introductory text was given to students to understand their pre-model of experiment design:

You are a researcher in an entomology laboratory and you have to take care of beetles and rolly pollies. To keep them in your terrarium, you have to find out what kind of environment your animals like. First, you want to find out your bugs ***moisture preference****. How can you do that?*

As shown in Table 3 only six of the students were able to narrow the range of problem as a research question. In other words, remaining three were not structured sufficiently to find out moisture preference. In this case, students had difficulties listing independent, dependent and control variables. However, based on analysis, the preconception of students' designing an experiment had some components of the procedure.

After the students set up the experiment, they started collecting data for bugs` moisture preference. Their observations were based on comparisons of bugs` preference given different kinds of soil conditions- dry, moist, and wet. The data obtained included much more comparison than their first attempt in session A1. Here is an example:

Student 9: *Beetles are really like going under the soil. All are likes dry soil. I can definitely see that they dislike the wet soil when they get close they move away very quickly in the other direction.*

3.1.3. Session A3: Responding to light

In this last session of the experiment with bugs, the students followed the same procedure as in session A2. They designed an experiment to examine bugs' light preferences and then revised their design with the tutoring provided. Then, they collected the data and made inferences according to the evidence they gathered. As shown in Table 3, all of the six students defined their research questions.

Student 1: *How do roly-polies react to light and which do they prefer?*

They tried to define the variables. However, they were still confused about dependent and independent variables. On the other hand, five students listed their control variables. Although there seems to be an improvement in students` model of experiment design, there is still room for development.

People sometimes express their plan as a model. This expression can be presented with equations, graphs, or computer simulations (Harrison & Treagust, 2000). In this study, two students introduced their designs by drawing a picture. Figure 3 presents one of these drawings.

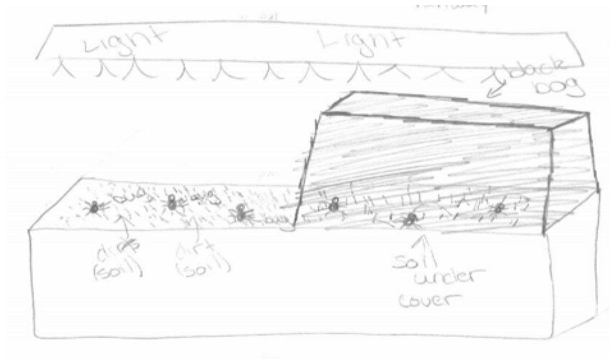


Figure 3: Student's Model to Experiment Bugs` Light Preferences

In session A2, student1 tried to bring together her observation as follow:

Student1: *rolly pollies try to bury themselves because their instinct is go under dry soil to find moist soil*

The student then revisited her ideas in session A3 and confronted another possibility:

Student1: *So far, after 15 minutes, the rolly-pollies like the dark areas. Perhaps this is because they like underground most of the time.*

3.2. Students' Model for Experiment Design About Goldfish's Reaction to Environmental Factors

3.2.3. Session B: The Effect of Water Temperature on Goldfish Behavior

In goldfish activity, the representation of students' model of designing an experiment was tested. This session is named as unknown situation since students` model building processes were examined with a new activity to test how much information was transformed from previous activities. In this activity the following task is given to the students:

You have experimented how pillbug and beetles need to moisture and light. Using your experience, design an experiment to observe the effect of water temperature on goldfish behavior.
Here some clues about the factors of your experiment:
· all fish must stay alive
· each fish can stay out of water for a maximum of 30 seconds
·each fish must have at least 4 minutes of recovery time for getting used in its new environment.
· water temperatures can range from 15 to 30 degrees of Celsius, depending on the species of fish - know the temperature limits of your fish!

The presented data suggest that students` experiment designing skills have been improved. During the designing procedure, all the students defined the research question and tried to categorize the variables. Compared with previous sessions, it may be concluded that they developed inquiry skills. For instance, students' first design attempt of adjusting the water temperature did not work out. They expressed dissatisfaction with their investigations due to the unsatisfactory attempts. They described their experiment as "no good". Repeating the activity could have reduced their motivation, but telling them designing an experiment requires patience made a positive effect.

As can be seen in Table 4, all the students formed an inference about their experiments. Their inferences were more detailed compared to the previous sessions.

Student 5: *I learned that every animal has its own metabolism rate when the temperature goes up (hotter) the metabolism goes up. When the water is colder the metabolism goes down.*

Student 8: *As the temperature increases so does the metabolism. As the temperature decreases the metabolism decreases. I learned that size of temp of water and stuff really does matter.*

In sum, the results from an unknown situation (goldfish activity) suggest that the students have developed their experiment design models through strategies learned from the given instructions.

4. DISCUSSION AND CONCLUSION

The results from this study suggest that learning gains and inferences are obtained when the students do their own job in giving instruction. During these activities, the students became aware of building a model of experiment design. One may conclude that model building is a long process and without given specific instruction students may experience difficulties in building models. One should not expect from the students to fully understand every detail in such a short time. On the other hand, model building can also be thought as a learning cycle, which feeds the student curiosity and encourage them to learn more.

On the side note, some students were reluctant to touch animals in the beginning. However, observing others who had no difficulty proved to be an alternative model to the reluctant ones. By the end of the activities, they all gained confidence with animals.

Finally, the goal of science education should be teaching scientific investigation and inquiry skills. It means providing students with experience in hypothesis formulation and investigation design. Moreover, it introduces the way of decision-making as it is used in science, technology and social issues. It seems that model criticism and modification processes are promising activities for inquiry.

When information in environment is relevant to human's needs, it is more likely to be remembered (Langer, 1994). Imagine that you are teaching living organisms in science class. Each organism has a set of preferred environmental conditions in terms of their body skills. Memorization can be a way of getting this information into student's mind. However, making the information relevant is necessity to enable them to mindful. Therefore, allowing students to design the model of environmental conditions for different animals can enable them to construct their own knowledge. They need to discover appropriate environmental conditions for the animals. Otherwise, animals might die. In this way, students would have an opportunity to learn that a model can be used as a tool of inquiry and there is no need to memorize. In short, if we let students do their own job in giving instructions, they will develop their partial models, question them and try to construct target model by working on their initial model. As a result, it may be better if educators try to construct their instructions in terms of explanatory models instead of inductive reasoning or quantitative principles.

Since the study was an after school activity, the number of the participants was very limited. Only the students who were interested in science activities joined the science club. Therefore, the researcher could not control the number of the participants, their gender and their school success in science classes. And those were the limitations of the study. But, this research dealt only with creating a learning environment via-model construction to understand students' model of experimental design strategies rather than measured or compared their school success or the gender influence.

Taken collectively, the study was a case coped with developing a group of students' understanding and thinking process by model construction. Thus, the results could not be generalized. On the other hand, the results of this study raise a number of issues for educators and researchers addressing students' model building processes. Two avenues for further exploration could complement this study. The first avenue is studies about model-based teaching and learning in different domains with larger participants and the second avenue is studies about other influencing factors on model-based teaching such as school success, socio-economics situations, gender differences and culture. All these variables were left for future studies.

REFERENCES

Anderson, J. R., Boyle, C. F., & Lewis, M. W. (1990). Cognitive modeling and intelligent tutoring. *Artificial Intelligent, 42*, 7-50.

Boulter, C. (1998). What's going to happen in the eclipse tonight?: Rethinking perspectives on primary school science. *International Journal of Science Education*. *20*(4), 487-500.

Buckley, B. C. (2000). Interactive multimedia and model-based learning in biology. *International Journal of Science Education, 22*(9), 895-935.

Clement, J. (1985). *A method experts use to evaluate the validity of models used as problem representations in science and mathematics*. Paper presented at the meeting of the American Educational Research Association, Chicago.

Clement, J. (1988). *Learning via model construction and criticism: Protocol evidence on sources of creativity in science*. Massachusetts University., Amherst. ERIC Document Reproduction Service. ED 303 357.

Clement, J. (2000). Model based learning as a key research area for science education. *International Journal of Science Education*, *20*(9), 1041-1053.

Gilbert, J. (1995). *The role of models and modeling in some narratives in science learning*. Presented at the Annual Meeting of the American Educational Research Association, April 18-22. San Francisco, CA, USA.

Gilbert, S. W. (1999). *The model as a vehicle for understanding the nature and processes of science.* ERIC Document Reproduction Service. ED 443 657.

Gilbert, S. W. (1988). *Student knowledge of models and science: Some findings and relationships*. Paper presented at the meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MO.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education*, *22*(9), 1011-1026.

Ingham, A. M. & Gilbert, J. K. (1991). The use of analogue models by students of chemistry at higher education level. *International Journal of Science Education*, *13,* 193-202.

Langer, J. (1994). From acting to understanding: The comparative development of meaning. In W. F. Overton & D. S. Palermo (Eds.), *The nature and ontogenesis of meaning* (pp. 191-212). Hillsdale, NJ: Lawrence Erlbaum.

Osborne, R. J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education, 67*(4), 449-458.

Strauss, A. & Corbin, J. (1998). *Basics of Qualitative Research* (2nd ed.). New Delhi: Sage.

White, B. Y. (1993). Thinker Tools: Causal models, conceptual change, and science education. *Cognition and Instruction*, *10*, 1-100.

Extended Abstract

There is growing recognition that models play a fundamental role in the comprehension of science concepts. The general definition of model is a simplified representation of a system, which concentrates attention on specific aspects of the system. Consequently, model building process can be expressed as an organizer for understanding scientific knowledge and process.

This paper aims at enhancing students' understanding and thinking by model construction. Seventh grade middle school students from an urban public school participated in this study as a part of their weekly science club that met after the regular school hours. During the course of the study, the students investigated several common environmental factors about animals by collecting data, made drawings, constructed objects, and wrote journals. The use of journals allowed them to reflect on their experience and the abstract concepts. It also allowed the researchers to have indirect access to the models underlying the meanings students were making every week.

Similar sessions followed during research design. In sessions, students were given short texts describing the problem. In the first text, they were requested to design an experiment or make an observation to find out bugs` reaction to environmental factors. The aim of the first text was to understand their pre-model of designing an experiment. Following the first activity, they were given a tutoring text in order to help them organize their ideas. This session was named as intermediate formation. Consequently, they were expected to learn about not only the bugs' environmental preferences like moisture and light, but also designing an experiment. During this session, since they are excellent classroom animals, isopods and beetles were used.

The next step was testing the students` strategies in an unknown situation. The unknown situation, goldfish's reaction to environmental factors, was created to test the representation of students' model of designing an experiment. After several observations on goldfish, students created an experiment design based on the effect of water temperature on goldfish behavior. In sum, the researcher suggest two directions, one is *vertical direction* that students could construct their model of bugs' and goldfish's reaction to environmental factors and *horizontal direction* that they could develop their model of designing an experiment that is tested by the model of goldfish.

All data were in the form of paper and pencil. Iterative process of open coding was used to analyze the data. Students developed initial models, came up with analogies, and constructed newer models by improving the initial ones.

The results from this study suggest that learning gains and inferences are obtained when the students do their own job in giving instruction. During these activities, the students became aware of building a model of experiment design. One may conclude that model building is a long process and without given specific instruction students may experience difficulties in building models. One should not expect from the students to fully understand every detail in such a short time. On the other hand, model building can also be thought as a learning cycle, which feeds the student curiosity and encourage them to learn more.

Finally, the goal of science education should be teaching scientific investigation and inquiry skills. It means providing students with experience in hypothesis formulation and investigation design. Moreover, it introduces the way of decision-making as it is used in science, technology and social issues.

When information in environment is relevant to human's needs, it is more likely to be remembered (Langer, 1997). Imagine that you are teaching living organisms in science class. Each organism has a set of preferred environmental conditions in terms of their body skills. Memorization can be a way of getting this information into student's mind. However, making the information relevant is necessity to enable them to mindful. Therefore, allowing students to design the model of environmental conditions for different animals can enable them to construct their own knowledge. They need to discover appropriate environmental conditions for the animals. Otherwise, animals might die. In this way, students would have an opportunity to learn that a model can be used as a tool of inquiry and there is no need to memorize. In short, if we let students do their own job in giving instructions, they will develop their partial models, question them and try to construct target model by working on their initial model. As a result, it may be better if educators try to construct their instructions in terms of explanatory models instead of inductive reasoning or quantitative principles.

Since the study was an after school activity, the number of the participants was very limited. Only the students who were interested in science activities joined the science club. Therefore, the researcher could not control the number of the participants, their gender and their school success in science classes. And those were the limitations of the study. On the other hand, the results of this study raise a number of issues for educators and researchers addressing students' model building processes. On the top of all, even though the study has some limitations the findings show that model criticism and modification processes are promising activities for science education.